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**Development of Adaptive Constraints in Infants’
Perception of Form-Function Correlations**

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Dedication

I would like to dedicate this dissertation to my husband, Elliot Benjamin Rapp, who has provided me with endless support throughout my graduate career and helped me “keep my eye on the ball” on this long journey. I also want to dedicate it to our child, who is on the way, and has kept me company for the past eight or so months. The expected baby coming into our life has already brought so much joy and perspective, and we have not even met him yet; I know the best in life is yet to come.

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**Development of Adaptive Constraints in Infants’
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The course of infants’ cognitive development does not always follow a non-monotonic, steadily increasing trajectory whereby improvement is defined by infants’ expanding repertoire of abilities. In some cases, for example, their range of abilities narrows with development and is seen as an adaptive process. The purpose of the present study was to gain a better understanding of infants’ developing “adaptive constraints” on their processing of correlations between the appearance and function of features on an object. Fourteen-, 16- and 18-month-old infants were

tested in a habituation experiment to investigate the developmental differences in infants' sensitivity to three correlations: (1) within-feature form-function correlation (the appearance of a particular feature on an object and its function), (2) between-feature form-function correlation (the appearance of a feature and the function of a different feature on the same object), and (3) form-form correlation (the appearance of the two features on the same object). Using a between-subjects design, previous research has shown that 14-month-olds are sensitive to both within- and between-feature correlations whereas 18-month-olds are constrained and sensitive only to the within-feature form-function correlation (Madole & Cohen, 1995). The present study included three important changes to this previous research: (1) infants were tested on a form-form correlation in addition to the two form-function correlations, (2) infants were tested using a within-subjects design rather than between-subjects, and (3) in addition to testing 14- and 18-month-olds, 16-month-olds were also studied. It was found that 18-month-olds showed sensitivity only to the within-feature form-function correlation; whereas the 14- and 16-month-olds showed sensitivity to none of the correlations. These results are interpreted as evidence that because they are without constraints, the younger two groups of infants struggled with attending to all the information presented at once; whereas that the oldest group of infants benefited from their adaptive constraint to process only the within-feature form-function correlation. These findings have implications for our understanding of

the development of constraints on infants' processing of information as well as the methods used to study infants' sensitivity to correlations.

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Chapter 1

Introduction

Development is generally thought to follow an increasing, monotonic trajectory whereby infants or children improve with age, usually in either a stage-like or continuous manner. This characterization may be accurate when development is viewed at a distance, but when examined more closely the picture is not always so simple. At times, development appears to follow a path of decline and, in some cases, even a path that is U-shaped.

Consider, for example, infant development during the first two years. Around 6 months, infants discriminate between both native and non-native speech sound distinctions, but around 12 months they discriminate between two speech sounds only if they are part of the infants' native language (Werker & Tees, 1984a). Consider also that around 6 months infants discriminate between two faces either that are both human or both non-human, but around 9 months they discriminate only between two human faces (Pascalis, de Haan, & Nelson, 2002). Both of these examples demonstrate that in some instances infants are initially less constrained in their responses to the world around them and with development become more selective and seemingly more adapted to their environment. Importantly, the findings also negate the traditional notion that development always entails an improvement in ability.

“Narrowing” appears to occur not only with simple discrimination as described above, but also with more sophisticated abilities. For example, after developing sensitivity to the correlation between internal and external features of both upright and inverted faces (i.e., holistic processing) around 4 months of age, infants around 7 months of age show sensitivity to this correlation only in upright faces (Cashon & Cohen, 2003; 2004). Consider also infants’ perception of form-function correlations. Fourteen-month-olds are sensitive to the correlation between the shape of a feature of an object and its function (a meaningful correlation) as well as the correlation between the shape of a feature of an object and the function of another feature (an arbitrary correlation). Eighteen-month-olds, however, show evidence of sensitivity only for the meaningful correlation (Madole & Cohen, 1995). Finally, consider findings in infants’ word-object associations. Whereas 8-month-olds discriminate between two similar sounding nonsense words, such as “bih” and “dih,” when each is paired with an object, or two less similar sounding nonsense words, such as “lif” and “neem,” 14-month-olds can only discriminate the less similar sounding words when presented with an object (Stager & Werker, 1987). Thus, “narrowing” is not limited to simple discrimination studies or to infants in the first year, but rather it can occur on lower- and higher-level tasks and with infants of any age.

Despite findings, such as those described above, in which infants appear to struggle with a task that was not problematic for them at an earlier age, most theories

of development make no effort to provide a coherent explanation of development that does not follow a steady upward trajectory. There are, however, a few notable exceptions that might provide some insight into the findings described. In particular, consider theories posited by Gottlieb (1991) as well as Greenough, Black and Wallace (1987). Both theories address fluctuations in development and are centered on the effects of experience on brain development. Both theories state that as infants become more adapted to their environment, their responses become more closely tailored to the world around them. Thus, according to both views, experience can produce developmental curves that are not always monotonically increasing.

These theories have certain limitations, however. Most importantly, they were not intended to describe cognitive developmental differences, but rather they were meant to describe anatomical changes that occur in the brain. Although they may not be able to directly account for decreasing patterns of development in cognition, they may provide a nice metaphor. What is needed is a theory of development that accounts for curvilinear or non-monotonically decreasing patterns of cognitive development. In the following chapter results from the infant literature will be presented that reveal what appears to be “cognitive pruning” and other unique curvilinear patterns of development, such as U-shaped and N-shaped patterns. Possible explanations for these findings will also be discussed. Explanations based on information reorganization rather than permanent loss will be considered as a promising key to a better understanding of these curvilinear patterns. Particular

attention will be paid to a domain-general information-processing explanation of the N-shaped phenomenon. Finally, the findings of an empirical test of this information-processing explanation will be presented.

Chapter 2

Literature Review

Cognitive Pruning

Behavioral findings showing that certain abilities disappear during infancy have emerged in a number of areas of research, including infant speech perception, language acquisition, face perception, and even form-function perception. Often the decline in performance can be seen as an adaptive response on the part of the infant, possibly a step in becoming more attuned to the infant's environment and experiences.

Phoneme Perception. In the area of speech perception Werker and Tees (1984a) found that infants' sensitivity to the universal set of phonemes declines during the first year, presumably as a result of experience with their native language. Using a conditioned head-turn procedure, English-hearing infants from 6 to 12 months of age were tested on their ability to discriminate between speech sounds that were specific to their native English (/ba/ versus /da/), specific to Hindi (retroflex /Ta/ versus dental /ta/), or specific to a Native American language called Salish (/k'i/ versus /q'i/). Regardless of whether the infants' native or a non-native language was presented, infants at 6 to 8 months of age were able to discriminate the sound contrasts; infants 10 to 12 months of age, however, could do so only if the sounds were phonemic in their native language. According to the authors, the system may initially be sensitive to the universal set of speech sounds but later becomes fine-

tuned to remain sensitive only to those speech sounds functional in the infant's native language.

Language Acquisition. With slightly older infants, Stager and Werker (1997) found what appears to be a decline in performance in infants' ability to associate and discriminate word-object pairs. In a series of studies, 8- and 14-month-old infants were presented with the task of discriminating between words that were paired with objects. Age differences were found based on whether the words to be discriminated were minimally different (e.g., "dih" and "bih") or very different (e.g., "lif" and "neem"). To test this, infants were first habituated to one object paired with a nonsense word (e.g., "dih"). They were then tested with the familiar word-object pairing viewed during habituation as well as a pairing in which the word was novel (e.g., "bih"), but the object did not change from habituation. Dishabituation to the novel word-object pairing was thought to indicate that infants could discriminate between the words when paired with an object. It was found that the younger, 8-month-old infants had no trouble noticing the change in words regardless of whether the words were minimally different or not. The older, 14-month-olds however had more trouble. They were able to discriminate the words that were very different (e.g., "lif" and "neem"), but were unable to do so with the similar sounding words (e.g., "bih" and "dih"). Interestingly, unlike with the loss of speech sound sensitivity, losing the ability to discriminate similar sounding words does not appear to be an adaptive response to the infant's environment. In other words, it is hard to imagine

that infants live in a world in which they would not need to be able to discriminate and associate similar sounding words to different objects.

A study by Woodward and Hoyne (1999) also found evidence of pruning in infants' word-object associations, but in contrast to Stager and Werker's findings, it does appear to be an adaptive change. They found that in addition to a word, 13-month olds could associate a variety of sounds with an object, such as a squeak, a beeper, a siren, or harmonica. Older infants around 20 months of age, however, were found to associate only words with objects. Thus, it appears that infants may have come to learn, presumably based on their experience, that there is something special about a word-object pairing that does not exist for other sound-object pairings.

Face Perception. In addition to these findings in speech and language acquisition, findings in the area of infant face perception also reveal what appears to be a decline in performance during infancy. Again the developmental changes found in these areas may be an adaptive response to the infants' experiences. For example, Pascalis, de Haan, and Nelson (2002) recently reported that infants' ability to discriminate between non-human faces declines during the first year of life. In their study, 6- and 9-month-olds, as well as adults, were tested on their ability to discriminate between pairs of faces that were either both human or both Macaque. The authors found that the 6-month-olds, the youngest infants in the study, were able to discriminate between the faces regardless of the species of the faces. The 9-month-olds and adults, on the other hand, could only discriminate between human

faces. Presumably the ability to discriminate monkey faces gets lost due to a lack of experience with this other species.

Taking a more process-oriented approach to face perception, Cashon and Cohen (2003, 2004) found what appears to be a decline in performance between the ages of 4 and 7 months in infants' ability to process more than the independent features of a face. In this set of experiments, half of the infants were presented with upright faces and the other half were presented with inverted faces. All infants were habituated to two female faces and then received three test trials -- a familiar face, a novel face, and a "switched" face, which consisted of the internal features (i.e., eyes, nose, and mouth) of one of the habituation faces and the external features (the remaining outer features) of the other habituation face. By comparing infants' looking times to the switched and familiar test faces, it could be determined whether infants were processing the correlation among features or the independent features. It was reasoned that if infants processed independent features of each face they would not look longer at the switched face than the familiar face. If, however, infants were sensitive to the correlation among facial features, they should look longer at the switched face because it consists of a new combination of features. It was found that 4-month-olds were sensitive to the co-occurrence of internal and external facial features of an upright or an inverted face, whereas the 7-month-olds were sensitive to this co-occurrence only with upright faces (Cashon & Cohen, 2003, 2004; Cohen & Cashon, 2001). Thus, by 7 months of age infants appear to have lost the ability to

correlate the internal and external features of inverted, but not upright faces. Studies on adults also show an “inversion effect” such that adults have a more difficult time recognizing the configuration of an inverted face compared to an upright face (e.g., Freire, Lee, & Symons, 2000). Furthermore, there is a growing body of research that suggests, due to their extensive experience with upright faces, adults may be “upright face experts” (e.g., Gauthier & Tarr, 1997). Given that it is around 6 months of age that infants begin to sit up on their own and therefore presumably see more upright faces, it seems quite possible that the inversion effect found at 7 months is at least in part due to infants’ lack of experience with inverted faces. Thus, once again, infants appear to be becoming more selective and adaptive.

Form-Function Correlation Perception. Finally, other results also indicate an apparent decline in infants’ performance outside of the areas of speech perception, language acquisition and face perception. A set of experiments by Madole and Cohen (1995) investigated 14- and 18- month-old infants’ ability to detect a correlation between the form and function of parts of an object. Infants were shown four events during the habituation phase demonstrating whether the set of wheels of an object rolled or not, and whether the particular top of the object spun or not. In the first experiment, these events consisted of meaningful correlations whereby the form of the wheels predicted whether they rolled or not (e.g., large, red wheels rolled and small, yellow wheels did not) and the form of the top predicted whether it spun or not (e.g., person-toy spun and tree did not). In the test phase, infants were presented

with events that demonstrated a disruption of the form-function correlations (e.g., small, yellow wheels now rolled, or tree now spun) and infants in both age groups noticed when these correlations were disrupted. In the second experiment, infants were shown more arbitrary correlations during habituation whereby the form of the wheels predicted the top's function and the form of the top predicted the wheels' function. Only the 14-month-olds noticed a disruption in the correlations in this experiment. Much like the other results mentioned, Madole and Cohen found that the older group of infants were more constrained in their processing of form-function correlations than the younger group. As the authors suggest, it appears that the older infants show sensitivity to the correlations that are more likely to occur in the real world and have lost sensitivity to the more arbitrary form-function correlations.

All of the findings discussed above demonstrate a phenomenon in which younger infants respond in some way to a broad range of inputs but older infants become limited in the range of inputs to which they will respond. In nearly every case mentioned, the developmental changes in infants could be described as an adaptive response, the result of infants becoming more attuned to their environment. Although many might agree with that interpretation, the underlying mechanisms that lead to infants becoming more attuned, or specialized, is not well understood. There are several explanations available, however, and these will be discussed in the following section.

Biological Mechanisms of Cognitive Pruning

The first two theories that will be discussed were not originally intended to account for the data described above, yet they have been cited as possible explanations for some of them (e.g., Werker, 1989; Pascalis, de Haan, & Nelson, 2002). The assumption that what gets lost, gets lost permanently is a cornerstone of each of the existing theories of brain development, one theory by Gottlieb (1991) and one by Greenough, Black, and Wallace (1987). As will be discussed later, this position may limit each theory's applicability to the findings discussed and highlight the need for an alternate explanation.

Gottlieb's Maintenance Function . Gottlieb (1991) proposed a theory of development that centers on the role of experience in brain development. Although his theory is based mostly on connections that get formed and maintained in the brain, it does incorporate one mechanism for a pattern of decline. In a recent summation, he explained: "...experience can play at least three different roles in anatomical, physiological, and behavioral development. It can be necessary to sustain already achieved states of affairs (*maintenance function*), it can temporally regulate when a feature appears during development (*facilitative function*), and it can be necessary to bring about a state of affairs that would not appear unless the experience occurred (*inductive function*)" (Gottlieb, 2001, p. 39).

Illustrations of these three developmental functions are shown in Figure 2.1.

Figure 2.1

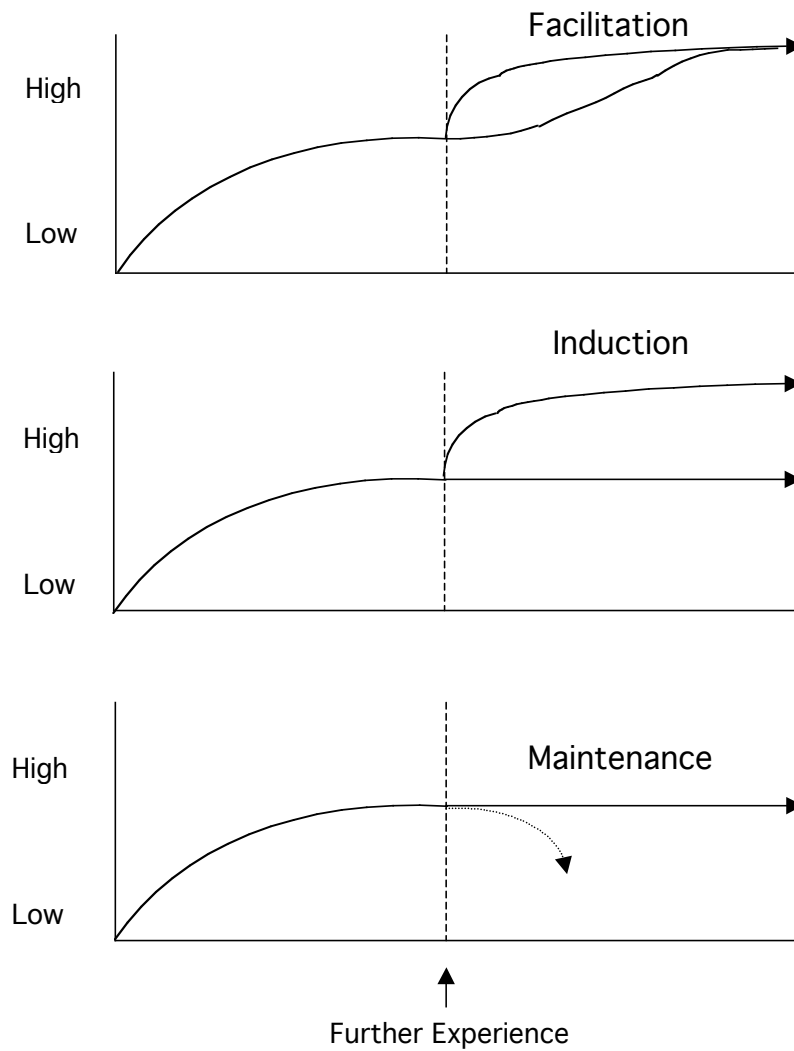


Figure 2.1. Adaptation of illustrations of three developmental functions showing the effects of experience posited by Gottlieb (1990).

It should be noted that in the role of experience in facilitation (top) and induction (middle), is to produce a positive effect or an improvement in performance whereas the role of experience in maintenance mode (bottom) is to preserve an already established level of performance (as illustrated by the solid line). Thus, according to Gottlieb's view, the role of experience is usually to either improve or maintain a high level of performance, with one exception. As shown at the bottom of Figure 2.1 in the maintenance function, the *absence* of experience can actually produce a decline (as illustrated by the dotted line). Thus, according to this view, the declines in performance across the various domains discussed previously would be the result of infants *not* having experience with certain input and thus losing the ability to represent these inputs. Although Gottlieb does not provide a name for this decline in performance, it is a very important aspect of the maintenance function and may help to explain one way that infants become attuned to their environment. It might also be possible, however, to find declines in performance that are the direct result of experience. This idea will be discussed more later.

Greenough, Black, and Wallace's Experience-Dependent and Experience-Expectant Processes. Also focusing on the effects of experience on brain development, Greenough, Black, and Wallace (1987) developed two views of how the brain can become specialized or attuned to its environment. These two processes of information storage have been termed *experience-expectant* and *experience-dependent* processes.

Experience-expectant information storage describes an information storage process in sensory development whereby the particular information that gets stored in the system is the information that is normally experienced by all members of a particular species, such as certain visual input. The underlying mechanism, neuronally, is the overproduction of connections between synapses followed by a Hebbian-like process of pruning that includes maintaining those connections that get used and eliminating those that do not (Figure 2.2).

Figure 2.2



Figure 2.2. Adaptation of illustration of the process of experience-expectant information storage posited by Greenough, Black, and Wallace (1987). The solid line represents “overproduction” and “pruning” with experience; the dotted line represents them without experience.

An important characteristic of the experience-expectant process is that the overproduction, or synaptogenesis, occurs at a time when the system is expecting to receive some species-general experience. Thus, a hallmark of an experience-expectant process is that it should occur at roughly the same time for all members of a species. A second important aspect is that the effects of the subsequent pruning cannot be reversed. As Greenough et al. wrote: “At the neural level, the irreversibility appears to arise in at least some cases because a set of synapses has become committed to a particular pattern of organization, while synapses that could have subserved alternative patterns have been lost.” (p. 546).

The experience-dependent process also involves pruning, however, it is thought to differ from the experience-expectant process in that the overproduction of synaptic connections that precedes pruning, occurs in response to experience rather than in expectation of having an experience (Figure 2.3).

Figure 2.3

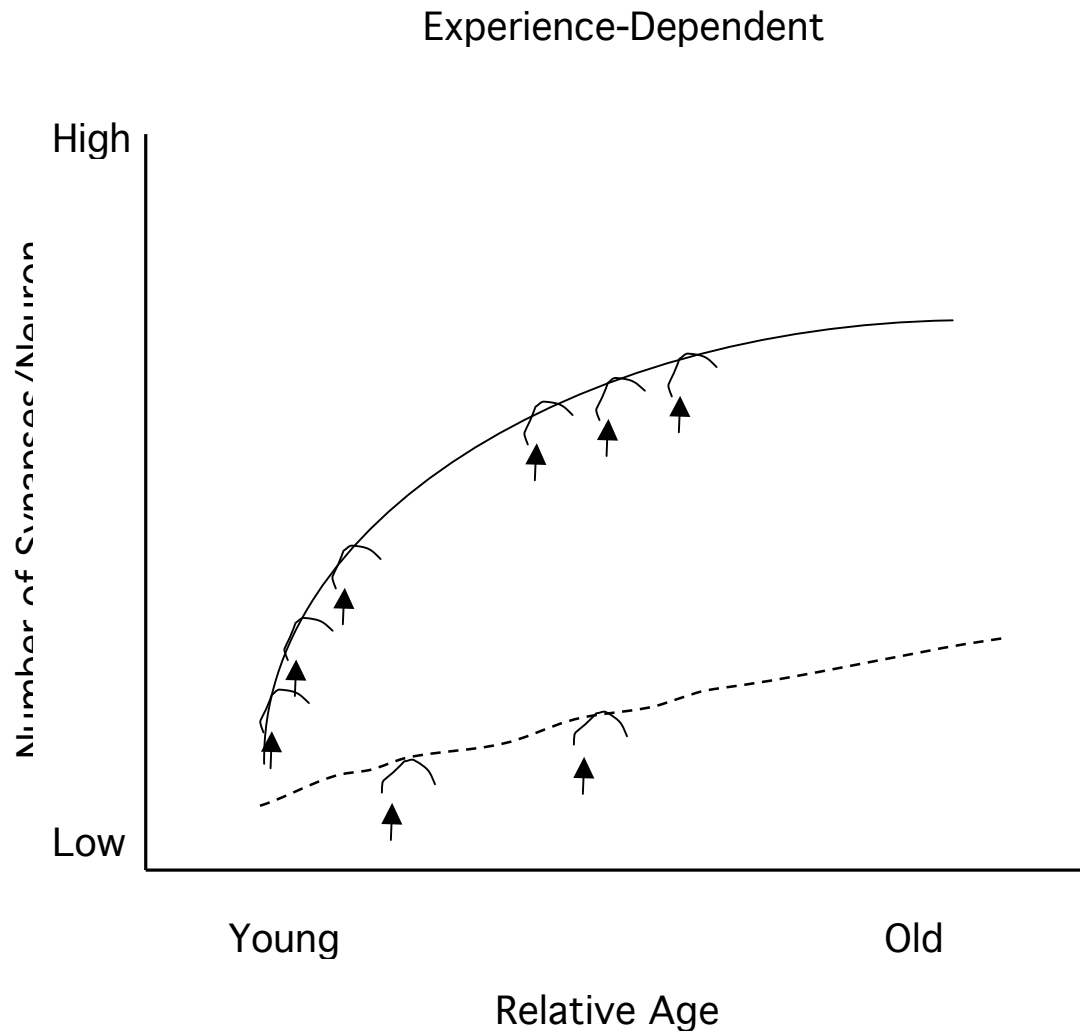


Figure 2.3. Adaptation of illustration of the process of experience-dependent information storage (Greenough, Black, & Wallace, 1987). Again, the solid line represents “overproduction” and “pruning” with experience; the dotted line represents them without experience.

Hence, it is thought to occur later in development and may be experienced uniquely by an individual member of a species, as opposed to all members of a species. In other words, an experience-dependent process could occur at any point in time, not just early in the first year.

How well might either of these brain-based theories of development account for the behavioral data already discussed? Pascalis, de Haan, and Nelson (2002) have suggested that either of Greenough et al.'s proposed processes may account for the narrowing effect found in infants' species-specific face perception between 6- and 9-months of age (Pascalis, de Haan, & Nelson, 2002). They also posited that because infants' phonemic awareness (Werker & Tees, 1984a) becomes specialized around the same time period, one underlying mechanism might account for both. They termed the common developmental pattern, "perceptual narrowing." On the one hand, they argue, the similarity in timing of the narrowing might suggest that both are the result of an experience-expectant mechanism working on perceptual abilities during the first year of life. In this case, there would be an overproduction of synapses, initiated without experience, and subsequent pruning that might be related to several perceptual domains including face and speech perception. On the other hand, the authors acknowledged that the timing may have been a coincidence and that both sets of findings may have been the result of experience-dependent processes. In this case, the onset of certain experiences in each of the domains would induce an overproduction of synaptic connections, and further experience would help

determine which of these connections would remain and which would get pruned.

Either of these explanations seems plausible.

There is, however, one further challenge in trying to explain the behavioral pruning data presented so far. Subsequent studies in some areas show that seemingly lost behaviors can reappear at a later age. Thus, the loss is not necessarily permanent, and in some cases, it even appears to be very transitory. In the following section, evidence for more complex developmental changes, such as U-shaped developmental changes, will be presented as well as some possible explanations for these changes.

U-Shaped Development

Phoneme Perception Revisited. There are several examples of curvilinear developmental patterns in the domain of language acquisition. One such example is found in discriminating phonemic contrasts. As discussed earlier, during the first year of life infants seem to lose the ability to discriminate between non-native speech sounds. Other studies have shown that this ability to discriminate actually gets worse still after infancy, dropping to its lowest level around 4 years of age only to return again for some non-native contrasts during adulthood (Werker & Tees, 1983). For example, it has been shown that with extensive training, English-listening adults improve in their ability to make the Hindi /Da/ - /da/ discrimination (Tees & Werker, 1984; Werker & Tees, 1984b) and Japanese listeners improve on the English /r/ - /l/ discrimination (Pisoni, Aslin, Perey, & Hennessy, 1982). Sensitivity has also been

shown to return when vowels are used as stimuli (Polka & Werker, 1994). Finally, the results of an event-related potential (ERP) study show that even when adults do not indicate behaviorally that they can discriminate between certain non-native contrasts, the activity in their brain differs for the sounds and indicates that at least on some level the two non-native sounds are perceived differently (Rivera-Gaxiola, Csibra, Johnson, and Karmiloff-Smith, 2000; Rivera-Gaxiola, Johnson, Csibra, & Karmiloff-Smith, 2000). Such findings suggest that the loss of certain abilities may not be permanent and can return with experience. They also suggest that what may have once been viewed as pruning might be better described as following a U-shaped pattern of development.

Because the U-shaped pattern is inconsistent with Gottlieb's and Greenough et al.'s theories, Werker and her colleagues have argued that the developmental changes are more likely due to functional reorganization than to changes in the hard-wiring of the auditory system (Werker, 1995; see also Werker & Tees, 1983; Werker & Tees, 1984a; Werker, 1989, 1994). According to their view, infants learn that certain sounds are more relevant to their language than are other sounds. This leads older infants to use a linguistic system to evaluate speech sounds, which allows them to focus on aspects of the input that will help them distinguish meaning, rather than simply perceptual differences (Werker et al., 2002). In other words, the young infants around 6 months of age who appear to be "universal listeners" show a high performance in their discriminability because they are thought to be focusing on the

perceptual aspects of the sounds rather than the linguistic aspects; older infants and children, between 10-12 months and 4 years of age who appear to be the least sensitive to non-native phonemes, are thought to be using a language-specific mode of processing that focuses on the linguistic role of the speech sounds. They fail to do well on the discrimination task because, according to Werker and colleagues, they are highly constrained in using the language-specific mode and do not yet have the flexibility to attend simultaneously to perceptual information. Finally, adults are thought to have the ability to use either mode of processing, perceptual or linguistic, depending on the demands of the task. Thus, the dip in the U-shape is the result of the older infants and children being highly constrained to use the language-specific mode and not having the flexibility displayed by adults.

One question that remains, however, is how infants come to learn to attend to the meaningful aspects, or linguistically functional aspects, rather than to just the perceptual aspects of speech sounds. This question was recently addressed by Maye, Werker, and Gerken (2002). Specifically, they were interested in testing whether infants use the distributional properties of their language to help them determine which speech sounds may be functional in their native language, and ultimately reorganize their perceptual categories. In this study, 6- and 8-month-old infants were trained for 2.3 min on either a unimodal or bimodal distribution of speech sounds falling within the /da-/ta/ continuum. Half of the infants heard sounds that fell mostly near the middle of the continuum (unimodal distribution) and the other half

heard sounds that fell close to the /da/ and /ta/ ends of the continuum (bimodal distribution). After training, infants in both groups were tested on their ability to discriminate between the sounds /da/ and /ta/. It was found that the infants in the bimodal training condition could detect the difference but those in the unimodal condition could not. These findings suggest that infants' sensitivity to the statistical distribution of sounds in their language may be a factor in determining which input is more meaningful linguistically.

Thus, one possibility is that infants are little statisticians and begin to form categories of speech sounds around those they have calculated, or inferred, to be functionally important sounds. Another possibility is that the formation of these categories is related to their general cognitive level. In a study conducted nearly a decade ago, Lalonde and Werker (1995) sought to answer the question, does a relationship exist between general cognitive ability and the development of infants' speech perception? To investigate this issue, infants at 8-10 months of age were tested on their ability to discriminate non-native contrasts as well as their ability to form categories of objects (a task taken from Younger and Cohen, 1983) and to search for an object in a standard A-not-B search task. Previous studies have shown that infants show marked improvement on these tasks around 8-10 months of age. Based on their performance on the phoneme discrimination task, the infants were separated into two groups and then infants' performance from each of two groups was compared on the two cognitive tasks. The authors found that there was an

inverse relationship between phonemic sensitivity and performance on the cognitive tasks, that is, those who showed evidence of losing some phonemic sensitivity performed better on both the categorization task and the A-non-B search task. From this study alone, however, it cannot be determined whether the advanced cognitive abilities help infants develop linguistically, or vice versa, or whether there might be some other mechanism responsible for the development in each of the three areas. Together, these two studies suggest that infants' sensitivity to the statistical distribution of speech sounds and/or their general cognitive ability may be related to the reorganization that takes place in infants becoming more specialized in their perception of speech sounds.

Minimal Pair Word Perception Revisited. Just as findings have shown that the developmental pattern associated with phonemic awareness of non-native speech appears to follow a U-shaped pattern a collection of findings related to word-learning also point to a U-shaped developmental pattern in this domain. Recall that Stager and Werker found that 14-month-olds do not discriminate between minimal pair words when presented simultaneously with objects, whereas 8-month-olds do. According to the authors, 8-month-olds approach the task as a perceptual one, whereas 14-month-olds approach it as a word-learning task. The problem for these 14-month-old infants, as argued by the authors, is that they are novice word-learners and do not have the cognitive resources to deal with both associating words and objects as well as attending to the fine phonetic detail of minimally different words. This argument

suggests that these infants should be able to discriminate minimally different pairs of words if they are presented in the context of a non-word-learning task. In fact, a control study showed that when words were paired with a checkerboard pattern rather than an object, 14-month-olds were able to discriminate between minimal pairs.

In a recent study, Werker, Fennell, Corcoran, and Stager (2002) tested 14-, 17- and 20-month-olds and found that after “losing” the ability at 14 months to associate minimal pair words with objects, the ability returned by 17 months of age. In this set of experiments, infants were habituated to two minimally different words that were each paired with a different object. Following the habituation phase, infants were tested on a switch of the word-object pairing. It was reasoned that for infants to notice that a switch had occurred in the test phase, they had to be able to discriminate between the minimal pair words when they were paired with an object. Similar to what Stager and Werker (1997) found with their simpler version of this task, the 14-month-olds did not notice the switch although the 17- and 20-month-olds did. Together the findings from these two sets of studies suggest that infants’ ability to process minimal pair words when presented with an object changes with age, following a U-shaped developmental pattern.

Similar to the explanation provided for the U-shaped pattern in phonemic sensitivity, Werker et al. (2002) argued that reorganization, specifically a functional reorganization that entails a change in processing, could account for these data as

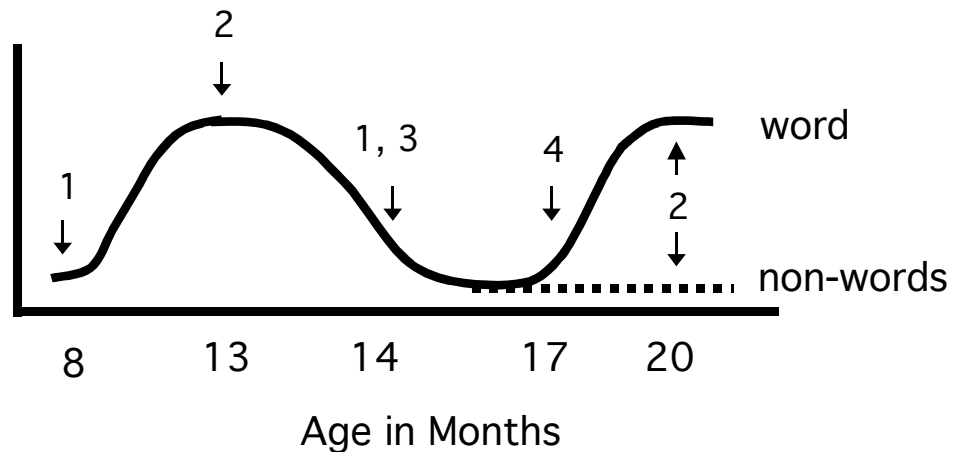
well. They argued that the 8-month-olds have no trouble dealing with the minimally different sounding words because they are treating the task as a simple perceptual one. The older age groups, on the other hand, approach the task as a word-learning problem. Fourteen-month-olds show a decline in performance because they are novice word learners and are struggling both with associating the sounds with objects and discriminating between two very similar sounds. Unlike 14-month-olds, 17- and 20-month-olds have become more proficient word-learners, have more cognitive resources to allocate to the fine phonetic detail of the minimal pair words, and thus are able to deal with both the cognitive demands of discriminating minimal pair words and associating them with objects. Some indirect evidence to support this idea is provided by their finding that infants' vocabulary size, which is presumably an indication of word learning ability, is correlated with the ability to succeed on this task around 17 months of age. It is not clear from this finding, however, whether an increase in ability to discriminate the minimal pair words results from having a larger vocabulary or whether improvements in both are simply due to general development and/or learning. Nonetheless, the finding is consistent with Werker et al.'s idea that the drop in performance is due to infants shifting from using a perceptual process to using a linguistic process, hence a functional reorganization.

N-Shaped Development

Word-Learning. If the minimal pair findings are considered in isolation to this point, the developmental pattern does indeed look U-shaped. However, there is

more to the story. When taken in conjunction with the results of Woodward and Hoyne, as well as some findings from another Werker study (Werker, Cohen, Lloyd, Casasola, & Stager, 1998), and when considered more from the perspective of word-learning than discrimination, the developmental pattern looks N-shaped (see Figure 2.4).

Figure 2.4



- 1 Werker, Cohen, Lloyd, Casasola, & Stager (1998)
- 2 Woodward & Hoyne (1999)
- 3 Stager & Werker (1997)
- 4 Werker, Fennel, Corcoran, & Stager (2002)

Figure 2.4. N-shaped developmental changes occurring in infant word-learning.

To illustrate this N-shaped pattern, first consider changes that occur in infants' ability to associate a word with an object between 8- and 14-months of age. Findings from Werker, Cohen, Lloyd, Casasola, & Stager (1998) show that whereas 8-month-olds do not associate a word and object, 14-month-olds do. Furthermore, Woodward and Hoyne (1999) also found that infants similar in age, 13 months, not only associate a word and an object, but also other sounds such a squeek, beeper, siren, or harmonica. Infants' improvement in performance on associating an object with a word, or sound, demonstrates the first segment of the N.

The next 2 segments of the N, the declining curve and subsequent improvement, are found when the previously discussed findings in Werker's lab are re-considered. Whereas 13- and 14-month-olds are shown to associate distinctly different words with objects, recall that Stager and Werker as well as Werker et al. (2002) also found that 14-month-olds have trouble when the words are minimally different. Thus, together these findings indicate that around 13-months infants may have peaked but by around 14 months they may be beginning to struggle in some ways. Subsequently, as discussed earlier, around 17 months infants begin to handle associating minimal pair words with objects more easily again. This is the start of the last segment of the N-shaped curve.

Finally, there is evidence that infants return to a highpoint at the end of the N-shaped curve. Werker et al. (2002), for example, report that 20-month-olds again have no trouble associating minimal pair words with objects and believe it is because

they are more expert word learners. Additionally, Woodward and Hoyne also found that infants at this age are more sophisticated word learners, that is, 20-month-olds associate a word with an object, but no longer the various other sounds like beeps and whistles. It seems that these infants seem to have learned that the word-object association is special, supporting the view that they have become more sophisticated in their word learning skills.

If the development of infants' word learning skills does indeed follow an N-shaped pattern, what might account for the dip in performance midway through the process? One possible explanation may be that the system becomes overloaded when trying to incorporate meaningful information, such as the special relationship that exists between words and objects, forcing infants to regress to a lower level of performance. According to this view, trying to incorporate additional information about the functional use of words overloads the system until it can be rebuilt, or reorganized, with the extra information included. This idea is based upon a set of information-processing principles of infant cognitive development proposed by Cohen, Chaput, and Cashon (2002). More on this important idea will be discussed in the following section on development in face processing.

In sum, studies on both phonemic sensitivity and minimal pairs show that although performance may drop, it can return to its earlier level. This U-shaped developmental pattern is difficult to reconcile with the idea that the initial loss of ability is due to a permanent loss of connections in the hardwiring of the brain, as

might be suggested by Gottlieb or Greenough et al.'s theories. The curvilinear pattern does, however, appear consistent with the idea of reorganization, such as the one posited by Werker and colleagues, involving a change in the mode of processing and the information to which the system attends. The pattern is also consistent with the information-processing interpretation, which suggests that there is a temporary system overload while additional information is being incorporated into the system. In the following section, curvilinear developmental patterns and reorganization will be addressed in the domain of face perception and the information-processing account will be discussed in more detail.

Face Perception Revisited. In addition to the evidence for an N-shaped pattern of development in infants' word learning, there is also evidence of such a pattern in infants' processing of faces. Recall that 4-month-olds correlate the features of upright as well as inverted faces whereas 7-month-olds do so only for upright faces. It appears on the surface as if some sort of pruning has occurred and the findings seem to fit nicely with Gottlieb's maintenance function or Greenough et al.'s process theories. However, again, there is more to the story. Before infants process the correlation of features at 4 months, subsequent studies by Cashon and Cohen showed that around 3 months of age they process the internal and external features independently. Thus, between 3 and 4 months age infants move from processing the internal and external features independently, to later correlating them. In testing 6 month olds, however, it was found that infants actually regress to processing both

upright and inverted face featurally again (Cashon & Cohen, 2003, 2004). Then, as discussed earlier, by 7 months of age infants regain the ability to integrate the internal and external features for upright faces, but not inverted faces. An experiment with 10-month-olds shows this 7-month pattern exists at 10 months of age as well. It appears that by 7 months of age infants have become constrained in the way they process upright and inverted faces based on what would be adaptive in their world. When one considers all the changes that occur between 3 and 10 months of age (see Figure 2.5), the pattern of development goes beyond pruning-- for upright faces the pattern now looks N-shaped and for inverted faces the pattern now looks like an inverted-U.

Figure 2.5

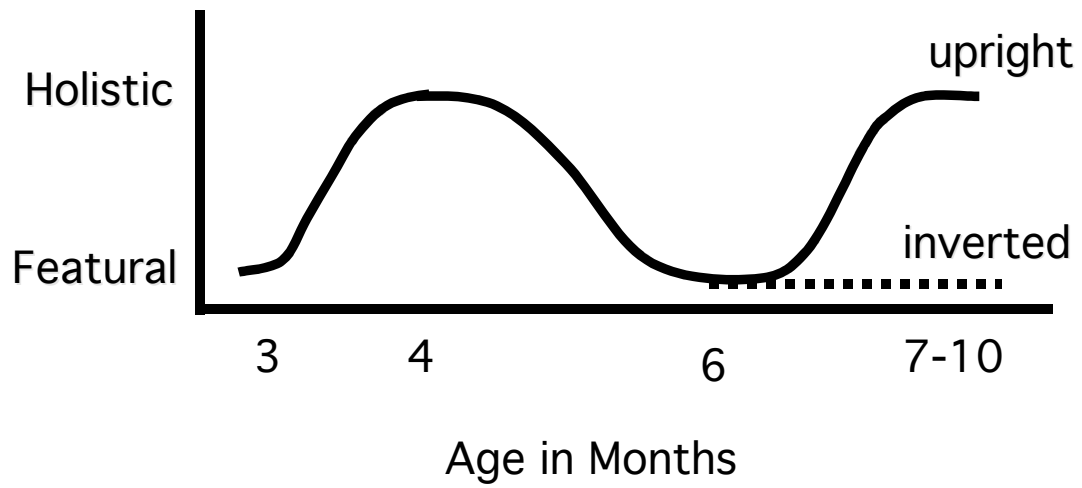


Figure 2.5. N-shaped developmental changes occurring in infant face perception (see Cashon & Cohen, 2003 and 2004).

Information-Processing Explanation of Curvilinear Developmental Changes and the Formation of Adaptive Constraints

The pattern that has emerged from both the findings on infant word learning and face processing is an N-shaped pattern. As with the other studies reviewed, these results are also examples of infants developing adaptive constraints on their perception of the world around them. But what might account for such a unique developmental pattern? Next, a similar explanation to the one provided for the changes found in word-learning will be discussed. As was alluded to in that prior discussion, the ideas are quite consistent with the information-processing principles of infant cognitive development put forth by Cohen, Chaput, and Cashon (2002).

Importantly each segment of the N-curve is quite consistent with some of Cohen et al.'s principles. The first section of the N-shaped curve is consistent with the principle stating that as infants develop they will move from processing the independent features of a stimulus to processing the correlation among those features. This principle, which is based on numerous studies with infants at different ages and in different domains, is consistent with the changes found between 3 and 4 months during which time infants develop the ability to correlate the internal and external features of a face. It is important to note that another characterization of this first highpoint on the N-shaped curve is that infants are still rather unconstrained in their processing. For example, in word-learning, infants at this point on the curve not

only associate words with objects but also a variety of non-linguistic sounds; in face perception, they correlate facial features of both upright and inverted faces.

According to the present view, the next section of the N, the first declining portion, is the result of experience and infants gaining the knowledge that certain correlations are more relevant to them. The problem is that initially trying to incorporate this additional information overloads the system. This idea is consistent with Cohen et al's principle stating that after infants process the integration of features, it is possible for the system to become overloaded when new information is added and causing it to regress to a lower mode of processing. This idea may help to explain why infants at 6 months regress to featural processing of both upright and inverted faces. It seems possible that around this age infants are attempting to incorporate additional social information about faces (Cashon & Cohen, 2003, 2004). Research on the still-face phenomenon, in which a person interacting with an infant suddenly shows no affect but maintains eye contact with the infant, suggests that infants at around 5 to 6 months of age are sensitive to the contingent social responses of others. Infants around 6 months of age are also beginning to show signs of stranger distress (Gaendbauer, Emde, & Campos, 1976). These studies provide at least a hint that around 6 months infants are starting to understand the social role of faces. It is also around this age that infants begin to sit up on their own. This may lead to a greater number of experiences with upright faces and make them more meaningful to infants than inverted faces. Thus, it seems possible that the dip in

performance around 6 months of age may be the result of an overload to the system as infants try to incorporate this new social information. An information overload may also explain why there is a dip in performance between 14 and 20 months of age with respect to minimal pair word-object associations. Infants may simply be at a point at which they are beginning to incorporate the meaningfulness of word-object associations and the system is easily overloaded.

How this additional knowledge is gained, however, is left unanswered at this point, but is a very important question that needs to be addressed empirically in the future. For the time being, however, the hypothesis is that this knowledge is gained through statistical learning, that is, learning that some correlations are more likely to occur in the real world than others. Although a good alternative to that view is that they may learn that certain correlations are more likely to be associated with some important outcome. Nonetheless, the main idea is that initially the system becomes overloaded by this additional information and it forces infants to regress to a lower level of performance (i.e., featural processing of faces or an inability to associate minimal pair words with objects).

The final upward swinging portion of the N-shaped curve can be described as a time of reorganization. The idea is that at this later point infants have successfully integrated the new knowledge and reorganized their representations. It is at this point also that they will demonstrate their adaptive constraints and will show sensitivity to only meaningful correlations (i.e., upright faces or word-object pairings only).

Chapter 3

Present Study

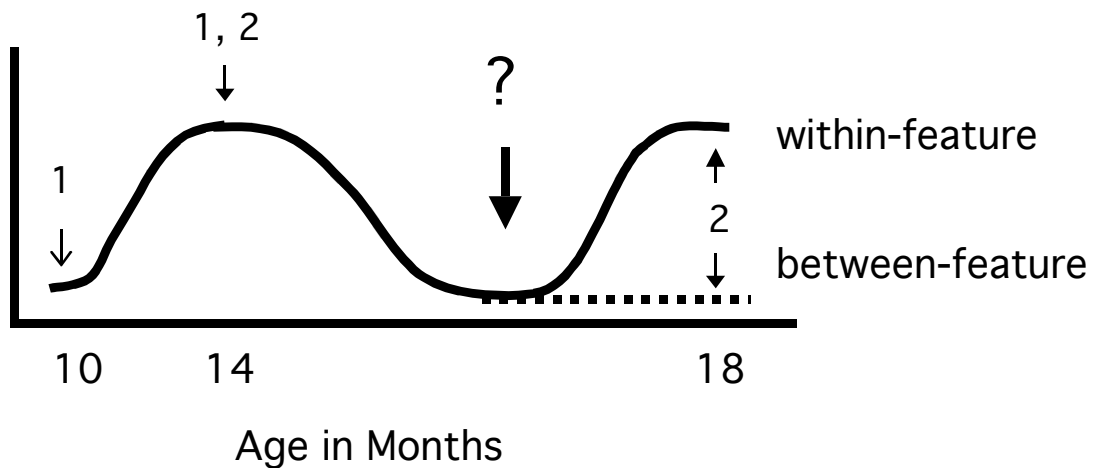
Together the studies discussed in the previous chapter show that infants, at times, follow a variety of curvilinear paths in the course of becoming more adapted to their environment. They also indicate that pruning (or narrowing), U-shaped, and N-shaped developmental patterns are domain-general phenomena and may be more prevalent than once realized. These patterns show the need for theories of development to be able to explain more than simple, linearly increasing curves in development as well as how an ability can return after it seems to have been lost. The information-processing approach presented provides at least a start in the right direction toward achieving these goals.

Thus, the next step is to begin to test some of the predictions made by the approach in other domains. One such prediction is that just prior to showing evidence of adaptive constraints, or a reorganization in information processing, infants will show evidence of their system becoming overloaded and breaking down. Another important prediction is that when infants first begin to process correlations, they will be unconstrained in the types of correlations they will perceive, but later will become more constrained by external knowledge.

The area of infant perception of form-function correlations, previously studied by Madole and Cohen (1995), is an ideal arena to test these predictions. As discussed earlier, Madole and Cohen showed that 14-month-olds are sensitive to

both within-feature and between-feature form-function correlations, whereas 18-month-olds are sensitive only to within-feature correlations. A previous study by Madole, Oakes, and Cohen (1993) also showed that processing the correlations between form and function develops between 10- and 14-months. As illustrated in Figure 3.1, this developmental pattern has many similar characteristics to the N-shaped curve found in infant word learning and face processing.

Figure 3.1



- 1 Madole, Oakes, & Cohen (1993)
- 2 Madole & Cohen (1995)

Figure 3.1. Developmental changes in infants' perception of form-function correlations.

At least two things are not known, however, about infants' processing of form-function correlations: First, does an overload occur between 14- and 18-months of age as predicted by the information-processing hypothesis? Second, are infants really less constrained in their perception of these correlations at 14 months than are infants at 18 months? In other words, would younger infants also have little trouble processing other kinds of correlations, such as form-form correlations?

Purpose

Thus, the purpose of the present study was two-fold. The first goal was to test the prediction that before showing evidence of having adaptive constraints, infants would show evidence of a system overload, or a U-shaped developmental curve. This goal was met by testing 14- and 18-month-olds, as Madole and Cohen had done, as well as 16-month-olds. The second goal was to test the prediction that infants at the youngest age would be the least constrained by the types of correlations they would process. This goal was met by testing infants not only on their perception of the within- and between-feature form-function correlations, as Madole & Cohen had done, but also on a third type of correlation – a form-form correlation.

Design Overview

The stimuli, design, and experiment itself were similar to that of Madole and Cohen's, but with several important changes. First, the present experimental design was within-subjects rather than between-subjects so that each infant could be tested on their sensitivity to each of the three types of correlations. Because it was

important in Madole and Cohen's study to keep the two forms uncorrelated, they had no choice but to use a between-subjects design; this was not an issue in the present study. Thus, infants were presented with four events during habituation, all of which maintained the three correlations: one within- and one between-feature correlation, as well as a form-form correlation. Having all the correlations presented simultaneously during habituation was thought to be more like the real world than presenting isolated examples of one type of correlations as done in Madole and Cohen. During test, each infant was tested on four events: One of these events was completely familiar and maintained all three correlations presented during habituation. The other three consisted of novel within- and between-feature form-function correlations, and form-form correlations. Second, the stimuli in the present study were computer-animated, whereas the stimuli in Madole and Cohen were videotaped. Computer-animation allowed for better consistency in timing and appearance across movies than the videotapes. Pilot data using these new stimuli indicated that infants showed great interest in the new computer-animated movies and no problems were expected by using them. Finally, the Madole and Cohen study was conducted by presenting the stimuli on a system that led to inter-stimulus intervals lasting 30 s or more. A more modern set-up involving software-controlled presentation of the stimuli, called "Habit," was used in the present study, which reduced the inter-stimulus interval to an insignificant amount of time.

Predictions

Predictions for infants' looking times based on age and correlation are presented in Table 3.1.

Table 3.1*Predictions for Infants' Mean Looking Times at Test Trials across Age*

Age	Correlations			
	Familiar	Form-Form ³	Meaningful Form- Function	Arbitrary Form- Function
14 mos.	↓ ¹	↑	↑ ¹	↑ ¹
16 mos. ²	↓	↓	↓	↓
18 mos.	↓ ¹	↓	↑ ¹	↓ ¹

¹Replication of Madole and Cohen (1985)²Age not tested in Madole and Cohen (1985)³Condition not tested in Madole and Cohen (1985)

In general, the results with the 14- and 18-month-olds were expected to replicate those of Madole and Cohen (1995). More specifically, it was expected that 14-month-olds would prove to be the least constrained in their perception of correlations and, thus, show sensitivity to all three types of correlations including the form-form correlation. Eighteen-month-olds were expected to be constrained in their processing and show sensitivity only to the within-feature form-function correlation. In other words, they were expected to behave similarly to those in Madole and Cohen (1995) and display an adaptive constraint.

The expectation for 16-month-olds was quite different from the other two ages. Because it was thought that at 16 months of age an infant's system might be struggling to incorporate the meaningfulness of certain correlations, it was expected that infants at this age would be overloaded and, thus, would not show sensitivity any of the three correlations.

Method

Participants. Fourteen- (13.5 –14.5 mos.), 16- (15.5-16.5 mos.) and 18-month-old (17.5-18.5 mos.) infants participated in this study. Data from 24, full-term habituated (12 female, 12 male) were sought for each age group. Letters inviting parents to participate were followed up with a phone call. Participants received a small gift of appreciation for participating (e.g., t-shirt, bib, cup, or mug).

A total of 192 infants were tested in the study. One-hundred twenty-one infants were excluded from the final dataset for various reasons, including not

meeting the habituation criterion or not looking long enough during at least one test trial to see both functions. A breakdown of the reasons infants were excluded is shown in Table 3.2.

Table 3.2*Infants Not Included in Final Dataset*

Reason	Age		
	14 mos. (<i>n</i>)	16 mos. (<i>n</i>)	18 mos. (<i>n</i>)
Fussy	9	5	6
Distracted by parent	1	1	0
Stopped by parent	1	1	1
Did not habituate	19	8	6
Did not see both functions during test	25	26	12

Because there were a high number of infants excluded from the final dataset, analyses of their data were conducted and presented in the Appendix. These analyses indicated that there was nothing systematic about the behavior of the excluded infants. The final dataset consisted of 23 fourteen-month-olds (11 female, 12 male), 24 sixteen-month-olds (12 female; 12 male), and 24 eighteen-month-olds (12 female, 12 male). These were infants who had habituated *and* had seen at least .5 s of each action on all four test trials.

Stimuli. Sixteen animated movies consisting of a blue object with wheels and a top feature were used as stimuli (see Figure 3.2 for examples).

Figure 3.2



Figure 3.2. Still photographs of example stimuli shown to infants in the present study.

In each movie the function of both the wheels and the top were demonstrated three times. As in Madole & Cohen (1985), the demonstration of the wheels' function was always presented first. At the start of each movie, the object was shown resting in the center of the screen. A hand then came onto the screen and touched the wheels. In some events the wheels began to roll while making a clicking sound and in some they made no movement or sound at all. Following this action, the hand reappeared on the screen and touched the top feature of the object. The top then either began to spin while making a swishing noise or made no movement or noise. This sequence then repeated two more times. Each movie lasted 28 seconds.

As in Madole and Cohen (1985), the object in the movies consisted of one of two types of wheels and one of two types of tops, both of which varied across the movies. In half of the movies, the wheels were large and red with white dots; in the other half, they were small and yellow with black stripes. Similarly, in half of the movies, the top was green and similar in shape to a smoke stack; in the other half, the top was purple and similar in shape to a whistle. The body of the object, which was held constant across all the movies, consisted of a blue block with an orange, smiling face in the center. The different combinations of the two tops, two wheels, as well as their functions resulted in 16 different movies.

Procedure. Following a brief interview infants were taken to the experimental room and placed on a parent's lap facing a 17" computer monitor roughly 120 cm away. A low-light camera placed under the monitor allowed the

infant to be seen by the experimenter in an adjacent room via a small television monitor. The experimenter measured each infant's looking times at the time of the session via the camera-television setup. In addition, each session was recorded on a DVD for later playback and inter-rater reliability purposes. For each age group, reliabilities were performed on 8 (33%) randomly chosen infants that were included in the final dataset. Data from the first four habituation trials, the last four habituation trials, and the four test trials were examined. The average correlation between the original and reliability data was .99.

Regardless of whether or not infants met the habituation criterion, all experienced both a habituation and a test phase. In the habituation phase, each infant was shown four events in which the appearance of the top, the appearance of the wheels, and the function of either the top or the wheels were all correlated. Infants were randomly assigned to either the wheels-function or the top-function condition. For those in the wheels-function condition, the function of the wheels (whether they rolled or not) was perfectly correlated with the form of the top and the form of the wheels (see Table 3.3).

Table 3.3*Condition 1: Wheels-Function*

	Wheels		Top				
	Form ¹	Function ²	Form ³	Function ⁴			
Habituation Trials	1	1	1	1			
	1	1	1	2			
	2	2	2	1			
	2	2	2	2			
					Correlations		
						Within- Feature Form- Function	Between- Feature Form- Function
Test Trials	1	1	1	1	Form-Form	FAM	FAM
	1	1	2	1		FAM	NOV
	2	1	1	1		NOV	FAM
	2	1	2	1		NOV	NOV

Note: Bold type indicates correlated features.¹Wheels Form: 1 = Green Top; 2 = Purple Top²Wheels Function: 1 = Function; 2 = No Function³Top Form: 1 = Red Wheels; 2 = Yellow Wheels⁴Top Function: 1 = Function; 2 = No Function

For example, red wheels and green top would always be shown with functioning wheels; whereas yellow wheels and purple top would always be correlated with non-functioning wheels. Importantly, the function of the top would not be correlated with anything and, thus, varied randomly across the habituation events. For infants in the top-function condition, the function of the top (whether it spun or not) was perfectly correlated with the appearance of the top and the wheels, but the wheels rolled randomly. Again, the benefit of this within-subjects design was to allow infants to attend any or all three types of correlations during habituation.

Infants were presented with a maximum of 24 habituation trials. The order of the four habituation events presented to each infant was counterbalanced, in blocks of four trials, in a latin square design. The habituation criterion was based on a sliding window of 4 and a 50% decrement in looking time from the first four habituation trials. If an infant habituated prior to the 24th trial, the test phase automatically began on the subsequent trial; in all other cases, the test phase did not begin until after all 16 habituation trials had been presented.

In the test phase, all infants were shown the same 4 test events, although, the order of these events was counterbalanced in a latin square design. Consistent with Madole & Cohen (1995), both the top and the wheels functioned in all test events. One of the test events was completely familiar, exactly the same as one of the four previously seen habituation events (counterbalanced across infants) and maintaining all three correlations presented during habituation. The other three test events

maintained one type of correlation while violating the other two (see Table 3.3 & 3.4).

Table 3.4*Condition 2: Top-Function*

	Wheels		Top				
	Form	Function	Form	Function			
Habituation Trials	1	1	1	1			
	1	2	1	1			
	2	1	2	2			
	2	2	2	2			
					Correlations		
					Within-Feature		Between-Feature
					Form-Form	Function	Form-Function
Test Trials	1	1	1	1	FAM	FAM	FAM
	2	1	1	1	NOV	FAM	NOV
	1	1	2	1	NOV	NOV	FAM
	2	1	2	1	FAM	NOV	NOV

Note: **Bold type** indicates correlated features.¹Wheels Form: 1 = Green Top; 2 = Purple Top²Wheels Function: 1 = Function; 2 = No Function³Top Form: 1 = Red Wheels; 2 = Yellow Wheels⁴Top Function: 1 = Function; 2 = No Function

Thus, all infants were tested on their sensitivity to the three types of correlations: within-feature form-function, between-feature form-function, and form-form correlations.

Trials in both the habituation and test phases ended as soon as an infant looked away for 1s or looked for the maximum trial length, 28s. Also, infants had to look for a minimum of 2 consecutive seconds for a trial to count. If infants did not look for this minimum amount of time, after 20s the presentation of that stimulus ended. The attention-getter would then return and the same stimulus would be shown again.

Chapter 4

Results

As discussed in the previous section, differences in infants' responses to the three novel correlations in the test phase were expected across age. Because there are two novel correlations presented in each of three test events (an artifact of having both the wheels and top function in each of the test trials), however, three separate sets of analyses had to be conducted to test infants' sensitivity to each of the three types of correlation. For each type, two of the test trials maintained that correlation and two encompassed a novel correlation. Thus, to analyze the data for each type of correlation, infants' looking times to the familiar and novel correlations had to be averaged across the two test trials. Preliminary analyses of the test trial data revealed no significant effects of gender, condition (wheels-function vs. top-function), or test order, thus, these variables were excluded from the following analyses.

Within-Feature Form-Function Correlation

To investigate infants' sensitivity to the within-feature form-function correlation (see Figure 4.1), the averaged looking time data for the familiar and novel within-feature correlation test trials were analyzed in a 3 x 2 (Age x Test Trials) mixed-model ANOVA.

Figure 4.1

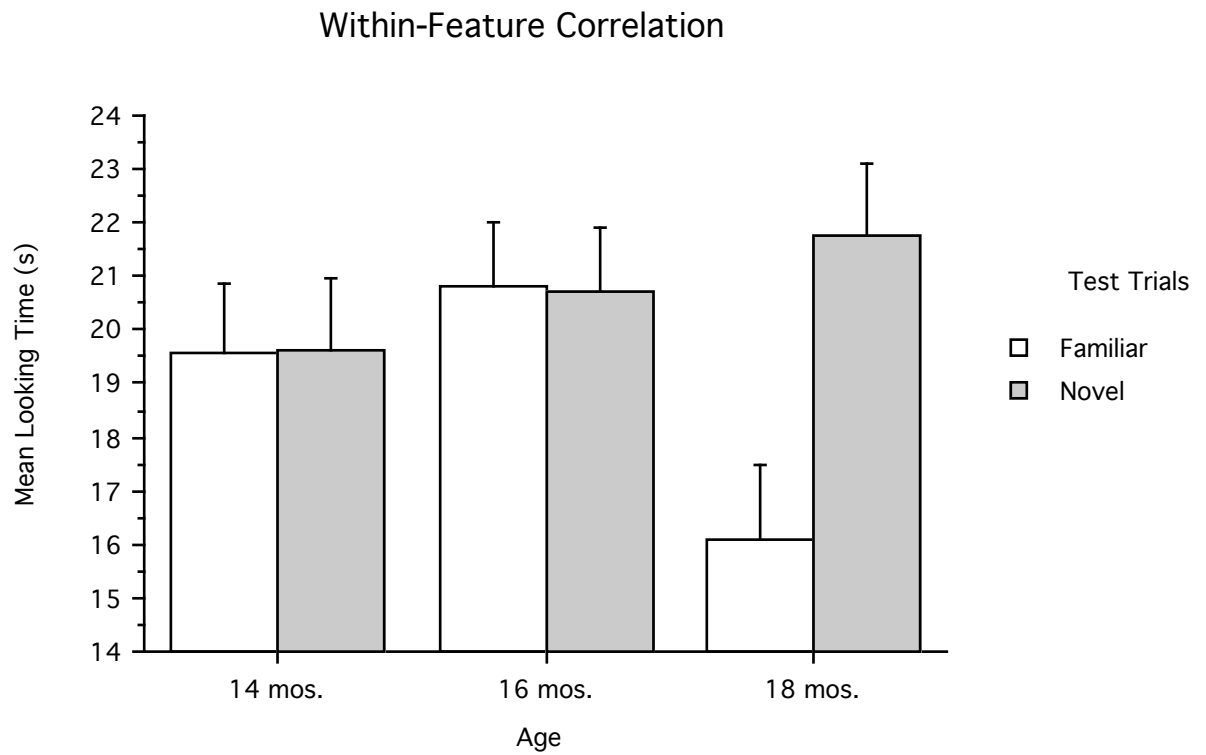


Figure 4.1. Averages of infants' mean looking times at the familiar and novel within-feature form-function correlation test trials.

Test trials was a within-subjects variable. The only significant effect in this analysis was an Age x Test Trials interaction, $F(2, 68) = 3.82, p = .03$. Subsequent analyses revealed a significant main effect of test trials for the 18-month-olds, $F(1, 23) = 6.82, p = .02$, but not for 14- or 16-month-olds. This finding indicates that the 18-month-olds looked significantly longer at the test trials with a novel than familiar within-feature form-function correlation, but the 14- and 16-month-olds did not.

Between-Feature Form-Function Correlation

To investigate infants' sensitivity to the between-feature form-function correlation (see Figure 4.2), a 3 x 2 (Age x Test Trials) mixed-model ANOVA was again conducted on averaged looking time data.

Figure 4.2

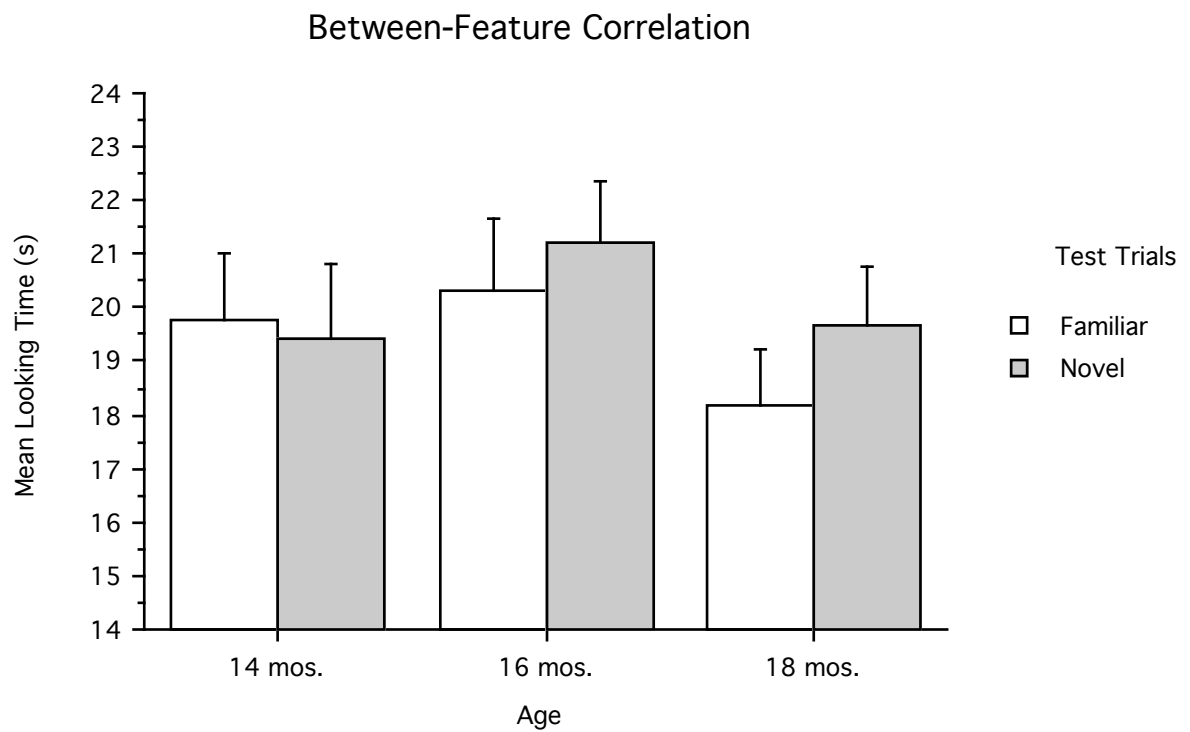


Figure 4.2. Averages of infants' mean looking times at the familiar and novel between-feature form-function correlation test trials.

However, in this analysis, the two levels of test trials were the average looking time of the familiar vs. novel between-feature form-function correlation. Again, test trials was a within-subjects variable. No significant effects were found indicating that no infants at any age did showed a significant preference for the novel between-feature form-function correlation.

Form-Form Correlation

To investigate infants' sensitivity to the form-form correlation (see Figure 4.3), a 3 x 2 (Age x Test Trials) mixed-model ANOVA was conducted on the averaged looking times of the familiar vs. novel form-form correlation test trials.

Figure 4.3

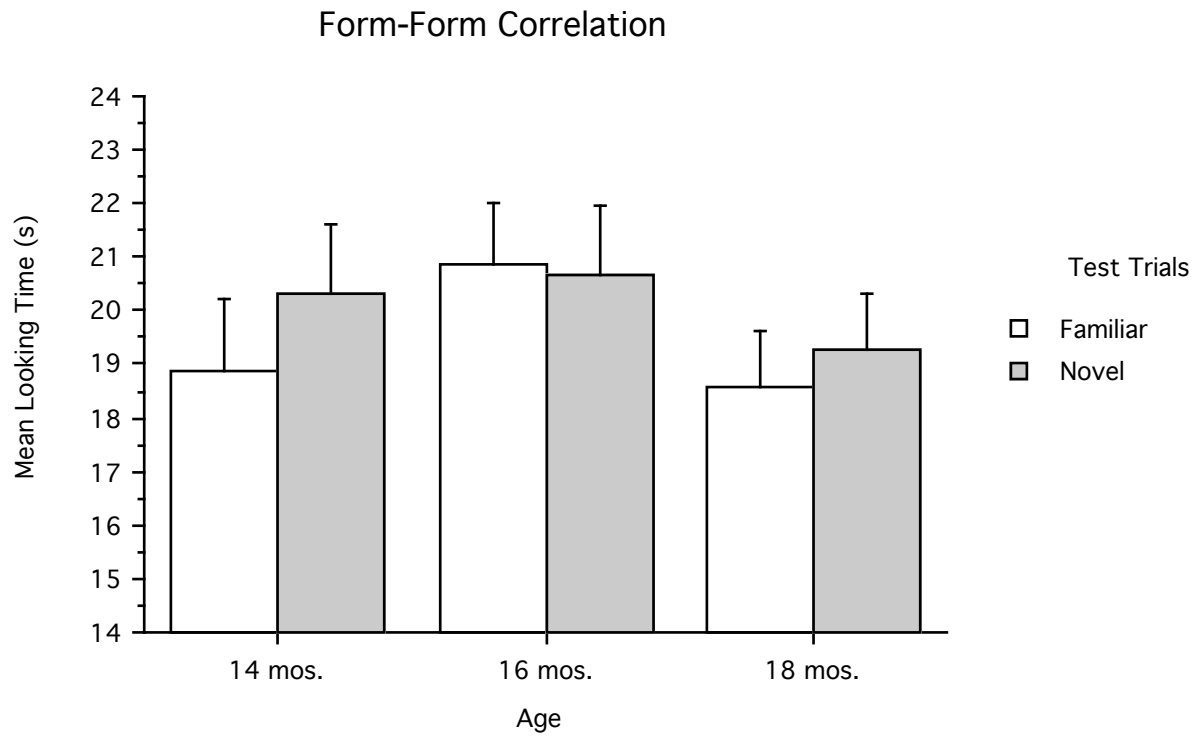


Figure 4.3. Averages of infants' mean looking times at the familiar and novel form-form correlation test trials.

Once again, no significant differences were found.

Habituation

Together, the previous three sets of analyses indicate that only the 18-month-olds showed sensitivity to any of the correlations, albeit only to the within-feature form-function correlation. Given that 14-month-olds have been shown to be sensitive to both the within- and between-feature form-function correlations in previous research (Madole & Cohen, 1995), it was surprising that no such evidence was found in this study.

One possible explanation for the lack of difference in 14- and 16-month-old infants' looking time to the familiar and novel test events is that they were fatigued and, thus, did not look long on any of the test trials. Another possibility is that they were attracted to the movement and/or sound of the wheels and top seen in the four test trials and responded for a lengthy time to all of them. Further analyses were conducted to tease apart these possibilities and better understand the aberrant behavior of both the 14- and 16-month-olds. It was reasoned that a drop in looking time from the beginning to the end of habituation with no sign of recovery to any subsequent test trials, including novel test trials, would suggest it was a problem of fatigue. On the other hand, evidence of habituation with recovery to *all* test trials might suggest they were responding to the action of the test events. Thus, infants' average looking times during the first four habituation trials, the last four habituation trials, the familiar test trial, and the average of the three novel test trials were entered

into a 3 x 4 (Age x Trials) mixed-model ANOVA. Again, trials was the within-subjects variable. These data are illustrated in Figure 4.4.

Figure 4.4



Figure 4.4. Infants' mean looking times for the average of the first four habituation trials, the average of the last four habituation trials, the familiar test trial, and the average of the three remaining novel test trials.

The only significant finding was a significant main effect for trials, $F(3, 204) = 2327.93, p = .0001$, although the Age X Trials interaction was found to be almost significant, $F(6, 204) = 44.68, p = .09$. Contrasts were conducted on each age group to investigate potential age differences (see Figure 4.4). The results confirmed that 14- and 16-month-olds behaved differently from the 18-month-olds and suggested that these younger infants did not respond to the familiarity vs. novelty of the test events. Both the 14- and 16-month-olds were found to look significantly longer at the beginning of the habituation phase than at the end ($F(1, 66) = 110.95, p = .0001$ and $F(1, 66) = 100.74, p = .0001$, respectively). They were also found to look significantly longer at the familiar test trial than at the end of the habituation phase ($F(1, 66) = 61.20, p = .0001$ and $F(1, 66) = 49.45, p = .0001$, respectively), yet, importantly no significant differences were found between the familiar test trial and the novel test trials. The 18-month-olds looked significantly longer at the beginning of the habituation phase than at the end of the habituation phase, $F(1, 66) = 67.18, p = .0001$, and significantly longer at the familiar test trial than at the end of the habituation phase, $F(1, 66) = 9.80, p = .003$. However, unlike the younger two age groups, these older infants did look significantly longer at the novel test trials than the familiar test trial ($F(1, 66) = 10.73, p = .0016$).

Together, these findings suggest that the older infants were responding to the familiarity and novelty of the events during the test phase, whereas there is no evidence to suggest that the younger two age groups were doing the same. Because

they were found to look longer at the familiar test trial than at the end of the habituation phase, it also does not appear as though they were fatigued.

Preference for Action

One possible explanation for the younger two ages' lack of differential responding to the test events may be that they were responding to the greater amount of movement, or possibly sound, present across all the test trial events (henceforth referred to as preference for action). To test if infants had a preference for the actions of the wheels and top at the time of the test phase, infants' looking times during the last four habituation trials were analyzed. For each infant, looking times on the last four habituation trials were coded as displaying the action of: (1) neither the wheels nor top, (2) wheels only, (3) top only, or (4) both the wheels and top (see Figure 4.5).

Figure 4.5

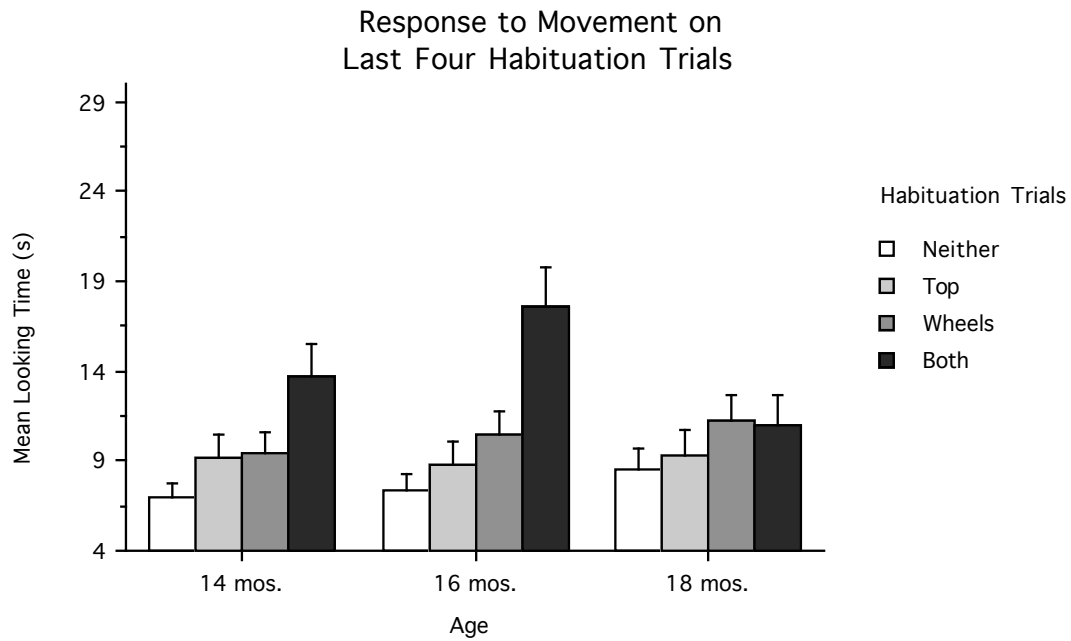


Figure 4.5. Infants' mean looking times on the last four habituation trials depending on the movement and/or sound of the wheels and top (i.e., movement from both, wheels only, top only, and neither).

One-way ANOVA's and a priori contrasts were conducted on these data within each age group. No significant differences in looking times were found for the 18-month-olds; however, a significant effect of action was found for both 14- and 16-month-olds, $F(3, 88) = 4.59, p = .005$ and $F(3, 92) = 9.43, p = .0001$, respectively. Further comparisons showed that at the end of habituation, both ages looked longer at trials with action from *both* features than at each of the other conditions: both vs. wheels alone (14-month-olds: $F(1, 88) = 4.94, p = .03$; 16-month-olds: $F(1, 92) = 541.85, p = .0006$), both vs. top alone (14-month-olds: $F(1, 88) = 5.95, p = .02$; 16-month-olds: $F(1, 92) = 15.86, p = .0001$), and both vs. neither (14-month-olds: $F(1, 88) = 13.63, p = .0004$; 16-month-olds: $F(1, 92) = 26.78, p = .0001$).

What is not clear from the previous analyses is whether infants had this preference from the start of the experimental session or whether they developed it during the habituation phase. If infants showed a preference from the beginning, it could explain why the younger two age groups did not appear to process any of the correlations – they may have focused solely on the actions and not attended to the other features. If infants did not show a preference in the beginning, it could indicate that there was something about the habituation experience that encouraged them to attend to the action. For example, the events presented during habituation may have been such a complex set of events that they overloaded the infants, forcing them to regress to a lower level of processing, one that involved attending to the actions of the events. To investigate these two possibilities, one-way ANOVA's and a priori

contrasts, similar to the previous analyses, were conducted on data from the first four habituation trials in each age group (as illustrated in Figure 4.6).

Figure 4.6

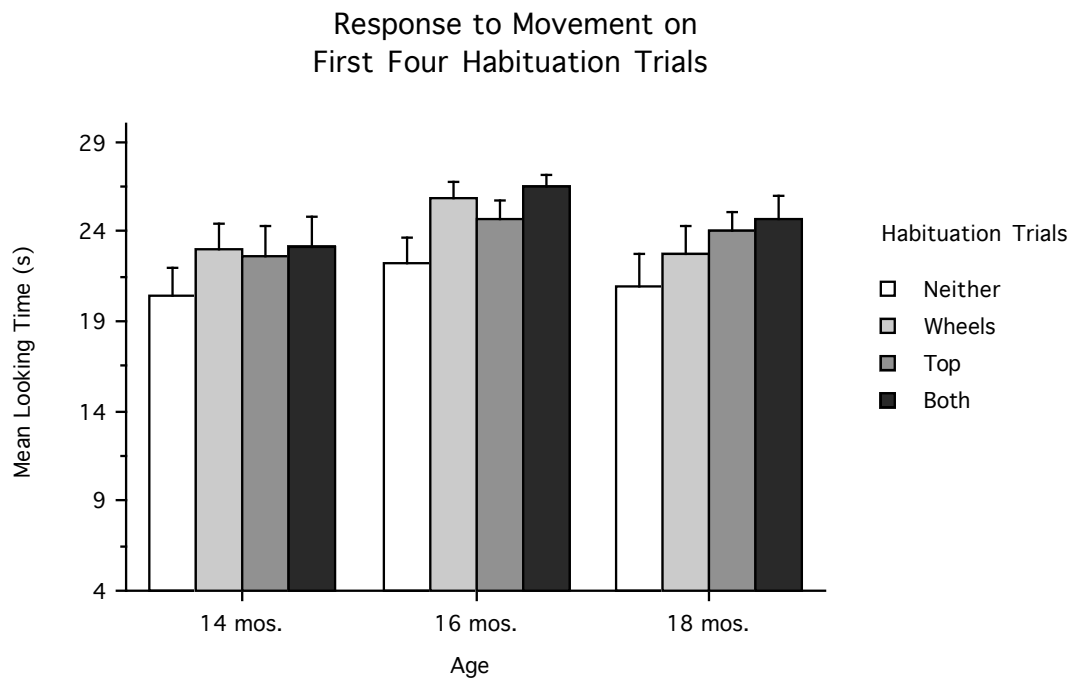


Figure 4.6. Infants' mean looking times on the first four habituation trials depending on the amount of movement and/or sound of the wheels and top (i.e., both, wheels only, top only, and neither).

There was no evidence found to suggest that the 14- and 18-month-olds showed a preference from the beginning of the experimental session. No significant differences in looking times at the beginning of the habituation phase were found for either of these two age groups. The results of the 16-month-olds' suggested, however, that these infants showed a preference for action, in some form, from the beginning of the habituation phase. First, a significant main effect for action was found in the one-way ANOVA, $F(3, 92) = 3.1, p = .03$. Second, contrasts showed that they looked significantly longer at trials presenting action from both features than neither, $F(1, 92) = 7.9, p = .006$. No significant differences were found in their looking times in the other two contrasts. In considering the two sets of analyses on the first and last habituation trials together, the results suggest that the 18-month-olds showed no preference for any event based on its amount of action. In contrast, the 14-month-olds may have developed a preference during the habituation phase. Finally, the results of the 16-month-olds suggest that the preference they showed for action from both features at the end of habituation and during the test phase was present, in some form, at the beginning of the experimental session and may have become enhanced during habituation.

Age Differences of Excluded Infants

As can be seen in Table 3.2, there were a relatively high number of infants who were excluded from the dataset because either they did not habituate or look long enough during at least one or more of the test trials to see both functions, which

would make interpreting their results difficult if not meaningless. Interestingly there also appear to be some age differences in the number of infants who were excluded for these two reasons. One, there appear to be more 14-month-olds than 16- and 18-month-olds who were eliminated because they did not habituate and, in fact, a chi-squared analysis confirmed that these age differences were significantly different, $X^2(2, N = 33) = 8.91, p = .01$. Two, it also appears that there are age differences in the number of infants who were excluded because they did not see both functions during the test. A chi-squared test confirmed that there were fewer 18-month-olds excluded for this reason than 14- and 16-month-olds, $X^2(2, N = 63) = 5.81, p = .05$.

Chapter 5

Discussion

The results of the present study provide further evidence that 18-month-olds are sensitive to the within-feature form-function correlation, as was previously reported by Madole and Cohen (1995). They also show that 14- and 16-month-olds, at least in this case, can have difficulty processing certain correlations; instead of showing sensitivity to any of the correlations in the present task, these younger two groups of infants were found to process the actions in the events. Thus, these results only partially replicate the findings of Madole and Cohen (1995), who reported that 14-month-olds are sensitive to both the within- and between-feature form-function correlations, whereas 18-month-olds are sensitive only to the within-feature correlation.

Why might the 14-month-old infants in this experiment have behaved differently from those in Madole and Cohen's studies? The answer probably lies in the different experimental methods in the two studies. Madole and Cohen tested infants in a *between*-subjects design whereby infants were trained on *either* the within- *or* the between-feature form-function correlation during habituation. In the present design, which was a *within*-subjects design, each infant was presented with *all three* types of correlations during habituation. Clearly the habituation phase in the present study was much more complex than that of Madole and Cohen and may have made the task extremely difficult for some of the infants. First, it would seem much

more difficult to monitor three types of correlations (i.e., within-feature form-function, between-feature form-function, and form-form), as demanded in the present study, than just one (within- or between-feature form-function), as demanded in Madole and Cohen.

Second, as shown in Tables 3.3 and 3.4, in the present study three of the features were correlated, but the fourth one varied randomly. By comparison, in Madole and Cohen's study none of the four features varied randomly; they were all involved in a correlation (see Tables 5.1 & 5.2).

Table 5.1

Madole and Cohen (1985): Within-Feature Condition

	Wheels		Top		
	Form	Function	Form	Function	
Habituation Trials	1	1	1	1	
	1	1	2	2	
	2	2	1	1	
	2	2	2	2	
Test Trials	1	1	1	1	Correlated
	2	1	1	1	Uncorrelated
	1	1	2	1	Uncorrelated

Table 5.2

Madole and Cohen (1985): Between-Feature Condition

	Wheels		Top		
	Form	Function	Form	Function	
Habituation Trials	1	1	1	1	
	1	2	2	1	
	2	1	1	2	
	2	2	2	2	
Test Trials	1	1	1	1	Correlated
	2	1	1	1	Uncorrelated
	1	1	2	1	Uncorrelated

Importantly, there do seem to be some cases in which having an extra feature vary randomly can hinder infants' sensitivity to the correlations among features. For example, Younger and Cohen (1986) found that both 7- and 10-month-olds were sensitive to the correlation among three features when all three were perfectly correlated; however, when two out of the three were correlated and the third feature varied randomly, only the 10-month-olds showed sensitivity to the correlation. Although this study was conducted with different aged infants and stimuli from the present experiment, it still suggests that having one randomly varying feature may have contributed to making the present task more difficult.

As reported in other research areas, it is not uncommon to find that by making the task more difficult, some infants, particularly relatively younger infants, will begin to have difficulty processing the information at a higher level and will show evidence of regressing to a lower level of processing (for discussion see Cohen, Chaput, & Cashon, 2002). There is evidence from the habituation data that supports this interpretation of the present results. Recall that the 14-month-olds *developed* a preference for the actions of both features during habituation, which is in stark contrast to the 18-month-olds who appeared unaffected by the amount of action in the stimuli across habituation. It seems that the 14-month-olds' processing was affected by what they saw during this phase. Instead of processing any of the relationships among the forms and the functions of the features during habituation, these young infants seemed to increase their attention to the movement and/or sound

of the two tops and wheels. One possible explanation for this increased attention to the action is that infants were overwhelmed by the abundance of information presented to them during habituation and, thus, struggled with attending to anything beyond the actions in the events. The notion that these infants became overwhelmed during habituation is further supported by the fact that more 14-month-olds were found not to habituate than the other two age groups, which is a result that would be expected if a group of infants was struggling to process the information presented during habituation. It could be argued that 14-month-olds simply had a preference for the action, but if this were the case, one would expect to see that preference from the beginning of the habituation phase. No evidence for this was found.

Assuming that the disparate results found with this younger age group are the result of overload caused by a more complex task, specifically a more complex habituation phase, it suggests that it would be more effective to test them with a less complicated habituation phase. Thus, a between-subjects design, similar to Madole and Cohen's, in which infants saw examples of either the within- or between-feature form-function correlations, or the form-form correlations during habituation might be more appropriate. An additional advantage to such a design would be that infants' sensitivity to a function-function correlation could also be tested, which might help further our understanding of the unconstrained nature of the younger infants' processing.

The behavior of the 16-month-olds, on the other hand, seems to have produced a different story. These infants were found to prefer the stimuli with moving and sound producing wheels and top from the beginning of habituation and maintained this preference to the end of the experimental session. These findings suggest that because they showed such unwavering attention to this type of event, they may not have had the problem of becoming overloaded. In fact, recall that the number of infants who did not habituate in this age group was much closer to the 18-month-olds than the 14-month-olds. Presumably this is because they were attending to the actions in the events in this task and possibly not even attempting to process the relationships among the parts. This suggests that even if tested in a between-subjects design, as described earlier, it is not clear that these infants would attend to anything other than actions. It seems possible that, as predicted, 16-month-olds might be in a state of transition and, thus, would have difficulty attending to the relationships or correlations presented to them. Another possibility, however, is that movement and/or sound are particularly salient to infants at this age and, thus, they would show sensitivity to a function-function correlation if tested. Again, a between-subjects design might help to disentangle these two interpretations.

Finally, it is important to note the differences between 18-month-olds and the younger two age groups. The results of the oldest group in the present study are consistent with the idea that they are constrained by what correlations they will process. Despite the more complex task of the present study, evidence was still found

that these older infants were sensitive to the within-feature form-function correlation, as previously reported by Madole and Cohen (1995). Given that the 14-month-olds may have been overloaded by the present task and appeared to have difficulty processing any of the correlations, it is even more remarkable that the 18-month-olds were able to process a relationship between the form and function of a feature. One possible explanation is that 18-month-olds simply have greater cognitive capacity to deal with the more complex task. Another possibility, however, is that the results provide an example of how having constraints on processing can be beneficial (see also Saffran, 2003). In other words, it could be that because they are more constrained in their processing it was easier for them to focus on the information related to the within-feature correlation without distraction from the extraneous information. This is one way in which the constraints on their processing may be very adaptive.

The notion of having adaptive constraints on the processing of information has also been explored by Saffran (see Saffran, 2003), but with respect to language learning. One of her main arguments is that the reason that there are cross-linguistic similarities is not that we have innate linguistic knowledge, but rather that languages have been, and continue to be, shaped by common learning constraints. Saffran further argues that one of the most important learning constraints is infants' use of statistical information provided in the input. She and her colleagues have shown that at 8 months of age, infants are able to abstract out "words" from a stream of speech

sounds using the statistical regularities in the input (Saffran, Aslin, & Newport, 1996). Although it is not usually discussed in these terms, picking up on correlations between forms and functions in a habituation task, such as in the present study, is essentially picking up on the statistical regularities in the input. Thus, this appears to be a domain-general mechanism (see also Kirkham, Slemmer, & Johnson, 2002). Although statistical learning may be a possible mechanism by which infants can form correlations in their mind, how or why constraints on infants' processing of certain correlations develops is still not well understood. This is obviously an important and difficult problem for researchers to untangle.

In sum, the goals of the present study were to investigate the prediction that before showing an adaptive constraint on their perception of form-function and form-form correlations at 18 months, infants would first be unconstrained in the types of correlations they could process, but then regress to a lower level of processing as they made the transition into incorporating external knowledge displaying a U-shaped pattern of development overall across age. A second goal was to further test the notion of what it means to be "unconstrained" at a younger age. Although neither clear evidence for a U-shaped developmental pattern nor for unconstrained flexibility in processing on the part of the youngest age group was found in the present experiment, the results may have been task dependent. They suggest that with an easier experimental task, the possibility of finding evidence for a U-shaped curve and less constrained processing on the part of the youngest age group is still on

the horizon. If found, the next important step will be to delve further into the learning mechanisms involved in the development of infants' adaptive constraints.

Appendix

Analyses of Original Dataset

Presented in Chapter 4 were the results of analyses conducted on data from infants who habituated *and* looked long enough during the test trials to see at least .5s of action from each the wheels and the top. Initially, however, many of the same analyses were conducted on an original set of habituators that included, in part, infants who saw less than .5 s of one or both actions. It was concluded that making any claims about whether these infants had or had not processed any of the correlations would be impossible if an infant had not seen one or more of the actions on a test trial. Thus, it was determined that analyses should be conducted on only on data who met the two criteria described above. This entailed replacing 6 cells in the 18-month-old group, 16 cells in the 16-month-old group, and 11 cells in the 14-month-old group.

Within-Feature Form-Function Correlation. Mean looking times during the test trials for familiar and novel within-feature form-function correlations of the original dataset are presented in Figure A1.

Figure A1

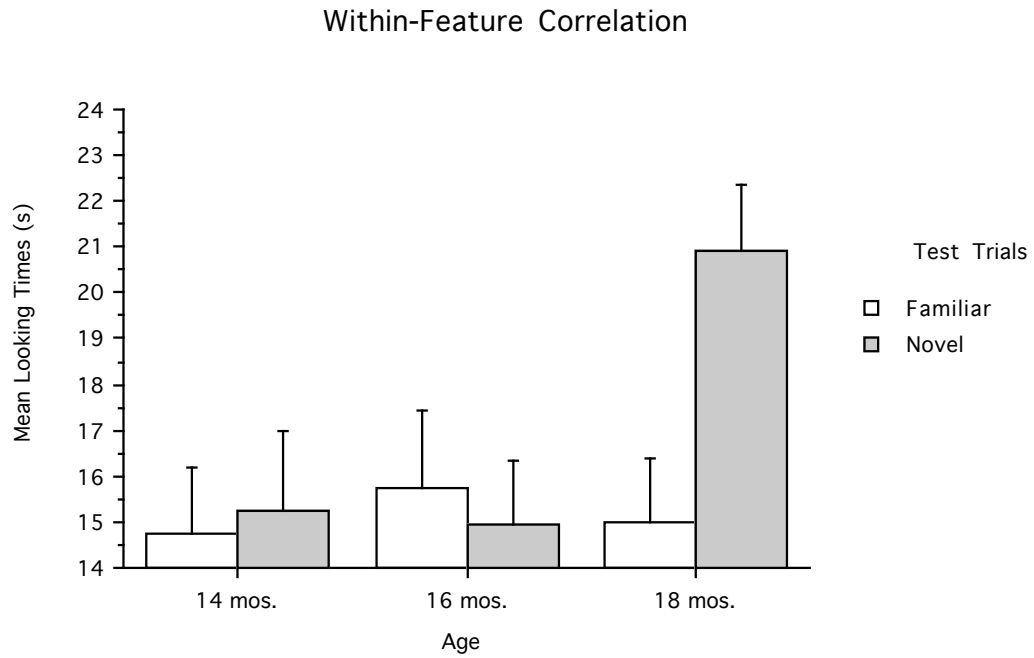


Figure A1. Averages of infants' mean looking times at the familiar and novel within-feature form-function correlation test trials shown with data from original dataset.

The same analyses were conducted on these data as were conducted on the final dataset to investigate infants' sensitivity to the three correlations. As with the original dataset, a 3 x 2 (Age x Test Trials) mixed-model ANOVA was conducted and a significant Age X Test Trials interaction emerged for the within-feature form-function correlation, $F(2, 69) = 3.07, p = .0527$. Again, the 18-month-olds were found to look significantly longer to the novel vs. familiar within-feature form-function correlation, $F(1, 23) = 5.49, p = .03$, whereas the 14- and 16-month-olds showed no significant differences in looking times. These results are very similar to those found with the final dataset. Even though the results with the 18-month-olds look very similar to those in the final dataset, it is most likely because very few infants' data had to be replaced and, thus, the results are driven by many of the same infants' data.

Between-Feature Form-Function Correlation. Infants' looking times during the test trials for familiar and novel between-feature form-function correlations are shown in Figure A2.

Figure A2

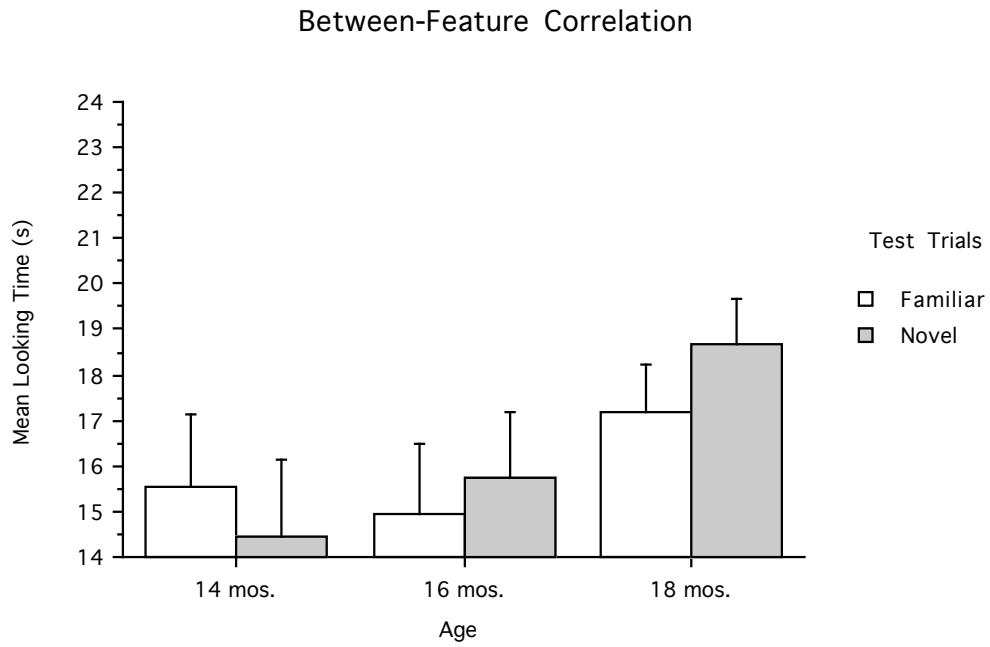


Figure A2. Averages of infants' mean looking times at the familiar and novel between-feature form-function correlation test trials shown with data from original dataset.

These data were entered into a 3 x 2 (Age x Test Trials) mixed-model ANOVA but no significant effects were found.

Form-Form Correlation. Infants' looking times during the test trials for familiar and novel form-form correlations are shown in Figure A3.

Figure A3

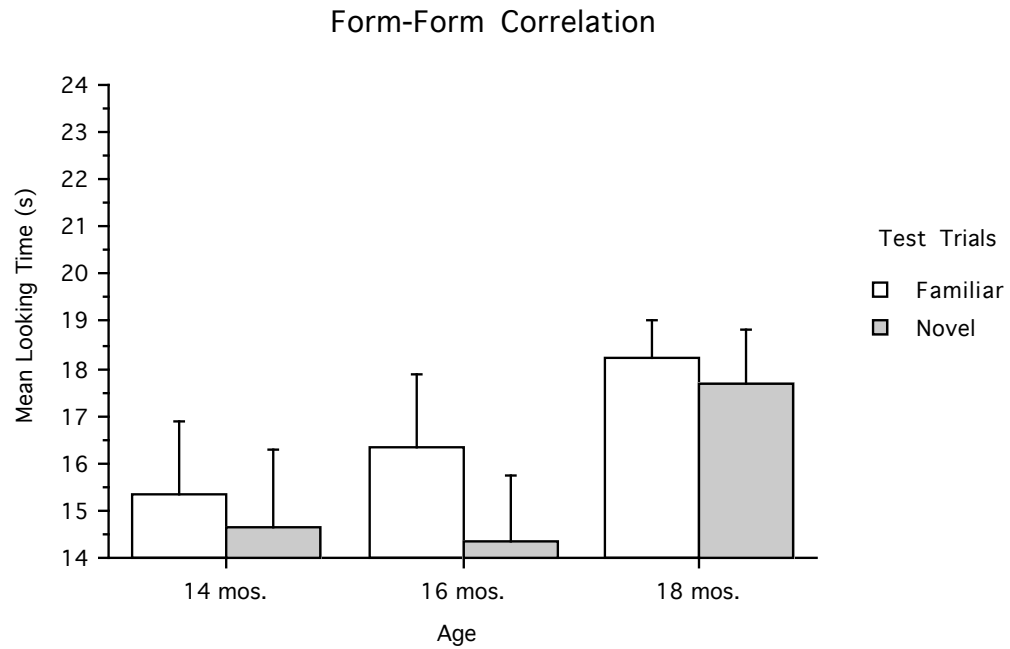


Figure A3. Averages of infants' mean looking times at the familiar and novel form-form correlation test trials shown with data from original dataset.

Again, no significant differences were found in the analyses.

Habituation. As with the final dataset, mean looking times of the first and last habituation trials, the familiar test trial, and the average of the novel test trials were analyzed across age. The pattern of looking times looked quite similar to that of the final dataset shown in Figure 4.4. These data were first entered into an ANOVA with gender, age, condition, and test trial order, but because gender was did not produce any significant results it was eliminated from further analyses. Unlike the findings with the final dataset, a 3-way interaction between trials, condition, and test order was found to be significant, $F(9, 72) = 2.88, p = .006$, indicating that a different pattern of looking across trials existed depending on the condition and test order. This result is difficult to interpret and may have been a spurious finding. Similar to the results found with the final dataset, a significant main effect for trials was also found, $F(3, 72) = 51.08, p = .0001$, and again, the Trials x Age interaction was almost significant, $F(6, 144) = 1.85, p = .09$.

In analyzing the pattern of looking across trials for each age group, the results looked similar to those of the final dataset. All three age groups looked significantly longer at the end of habituation than at the beginning (14 mos.: $F(1, 69) = 58.59, p = .0001$; 16 mos.: $F(1, 69) = 73.14, p = .0001$; 18 mos.: $F(1, 69) = 59.42, p = .0001$). Also, all three ages looked significantly longer to the familiar test trial than the average of the novel test trials (14 mos.: $F(1, 69) = 13.41, p = .0005$; 16 mos.: $F(1, 69) = 10.43, p = .01$; 18 mos.: $F(1, 69) = 6.36, p = .01$). Finally, similar to the findings with the final dataset, only the 18-month-olds looked significantly longer to the average of the novel test trials compared to the familiar test trial ($F(1, 69) = 7.48, p = .02$). It once again

appears as though the 18-month-olds habituated and had a novelty preference during the test phase, but that the younger two age groups did not.

Analyses of Excluded Infants' Data

It was argued that the reason the results of the original and final datasets were so similar is because only differences in looking times were found with the 18-month-olds and for the most part, the same infants' data were in both of these datasets. To test this idea, another set of analyses was conducted on the data only of infants who were replaced because they did not see enough of the actions during one or more test trials. ANOVA's were again conducted on the test trials for all three correlations. No significant differences were found due to different looking times during the familiar vs. novel test trials, however, a significant main effect for age was found for each correlation type (within-feature: $F(2, 59) = 4.54, p = .01$; between-feature: $F(2, 59) = 4.53, p = .01$; form-form: $F(2, 59) = 4.53, p = .01$). For all three correlation types, the main effect for age was due to 18-month-olds looking significantly longer in general during the test trials than 16-month-olds (within-feature: $F(1, 59) = 4.23, p = .04$; between-feature: $F(1, 59) = 4.21, p = .04$; form-form: $F(1, 59) = 4.22, p = .04$).

Analyses of Original Dataset Excluding Cells with Low Looking Times

A similar set of analyses was also conducted on the data of the original dataset with one exception: data from any test trial on which an infant did not look long enough to see at least .5s of both actions were omitted. The only significant effects found were a main effect for age for all three correlation types (within-feature: $F(2, 53) = 19.74, p = .0001$; between-feature: $F(2, 54) = 19.65, p = .0001$; form-form: $F(2, 55) = 19.41, p =$

.0001). For the within-feature correlation, the significant effect for age was because 16-month-olds generally looked longer than 14-month-olds, $F(1, 53) = 19.01, p = .0001$, and 18-month-olds generally looked longer than 16-month-olds, $F(1, 53) = 5.66, p = .02$. The same was true for the between-feature correlation, $F(1, 54) = 19.07, p = .0001$ and $F(1, 54) = 5.14, p = .03$, respectively. For the form-form correlation, however, only one significant contrast was found: 16-month-olds looked significantly longer in general than 14-month-olds, $F(1, 55) = 23.41, p = .0001$.

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